SWEEP OUTPUT CIRCUITS

Lesson T2C-12A

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

T2C-12A

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4141 Belmont Ave.

Chicago 41, Illinois

DeVRY Technical Institute

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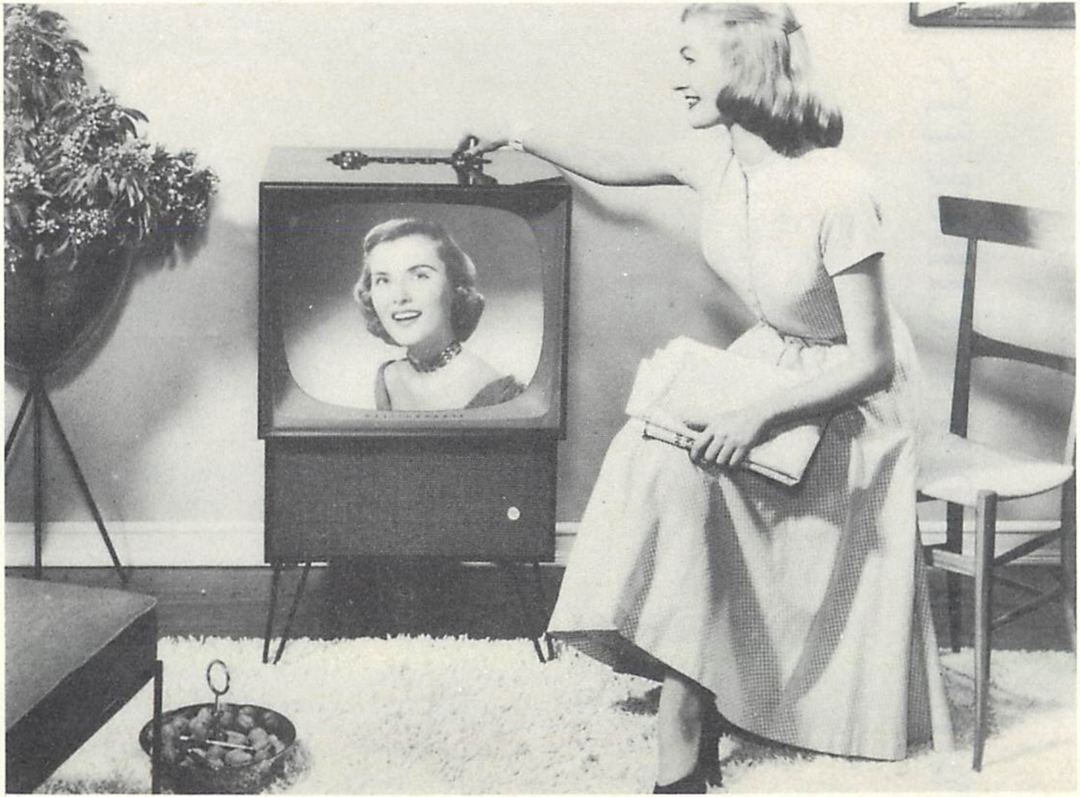

Whether sitting or standing, the viewer need not bend to reach the top-of-cabinet controls on this receiver.

Courtesy Westinghouse Electric Corp.

SWEEP OUTPUT CIRCUITS

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Character is like a tree and reputation like its shadow. The shadow is what we think of it; the tree is the real thing.

—Abraham Lincoln

SWEEP OUTPUT CIRCUITS

In the picture tube of the television receiver, the pattern of lines on the screen is produced by deflecting the electron beam from side to side rapidly, and from top to bottom relatively slowly. Since the electrons of the beam are negative charges of electricity, the deflection is obtained by means of a set of electromagnets. These electromagnets, or deflection coils, cannot attract or repel the beam electrons as a direct result of the electron charges. A magnetic field neither influences nor is influenced by an electric charge.

However, the electron beam is also an electric current. As such, it sets up a magnetic field about itself, the same as it would if it were carried by a conductor. As explained in a previous lesson, it is the interaction of this field with that produced by the deflection coils that causes beam deflection. Thus, the deflecting action is an indirect result of the charge on the beam electrons, since only moving charges can produce a magnetic field.

THE MAGNETIC DEFLECTION FIELD

Figure 1 shows a cross-section of the picture tube neck with the horizontal deflection coil mounted around it. To simplify the drawing, only a few coil turns are shown, and the vertical coil is omitted. An iron shell is placed around the coil. This shell shields the coil from stray magnetic fields, and serves as a low reluctance magnetic return path for the deflection flux lines.

As this view is taken looking toward the electron gun, the electrons of the beam are moving out of the page, as indicated by the small circle at the center. Curved arrows around the circle indicate that the magnetic field produced by the moving electrons has clockwise direction. During the portion of the deflection current cycle that the magnetic flux lines have the direction indicated, this flux interacts with the field around the beam to produce a force to the right. The heavy arrow denotes the direction of this force which acts upon and thus deflects the electron beam.

This same action is illustrated in Figure 2 which is a view looking downward from the top of the picture tube. Here, dots represent the cross sections of the deflecting flux lines within the deflection coil. The beam electrons move in a straight line from the electron gun to the deflection coil, then move in a straight path to the screen, having been deflected through the angle θ (theta).

The angle θ at which the beam is deflected from the axis of the tube is called the "deflection angle". For a given deflection coil, this angle depends upon the amplitude of the current in the coil. The product of the current in amperes and the turns in the coil is called the "ampere turns". Written as, NI, this product determines the magnetomotive force which produces the magnetic deflecting flux. The following expression gives the mmf in ampere turns required to produce a desired deflection angle when the anode voltage E_A, and the length l and air gap g of the deflection coil are known:

$$NI = \frac{.047\,\theta\,g\sqrt{E_A}}{l} \qquad (1)$$

where

N = number of turns in coil
I = coil current in amperes
θ = deflection angle in degrees
g = air gap in meters
E_A = anode voltage in volts
l = coil length in meters.

The derivation of this equation is given in Appendix A.

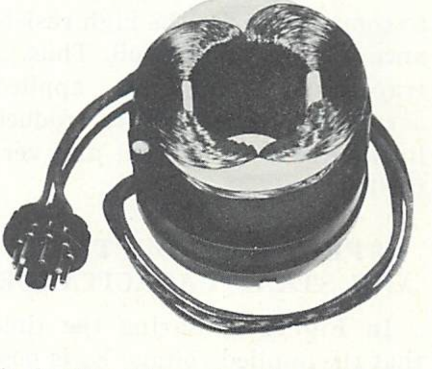
In a typical deflection yoke, the effective air gap is about .0635 meter (2½ inches), and the length of the horizontal coil is .09 meter ($3\frac{9}{16}$ inches). Suppose the picture tube anode is operated at 16,000 volts, and the required deflection angle is 70°. Substituting these values into equation (1), we can determine the ampere turns needed:

$$NI = \frac{.047 \times 70 \times .0635 \times \sqrt{16{,}000}}{.09} \text{ or,}$$

NI = 295 ampere turns peak to peak approximately.

DEFLECTION COILS

Represented by a block in Figure 3A, the sweep circuit applies a voltage E_A to the deflection coil. In this diagram, inductor L represents the inductance of the deflection coil, and R the resistance of its wire. Thus, the deflection coil is actually a series LR circuit. If the resistance were zero in this circuit, a rectangular voltage like the solid line curve of Figure 3B would produce a linear rise and fall of current in the deflection coil as shown in Figure 3C.



The deflection yoke produces the varying magnetic field required to move the beam in the manner which produces the raster on the screen.

Courtesy Merit Coil & Transformer Corp.

However, the resistance in the circuit alters the current waveform. If the resistance is relatively small, the current has a wave-form about like that of Figure 3D. This wave is approximately a sawtooth, and is employed in the low-resistance horizontal deflection coil. That is, linear horizontal sweep is obtained by applying a rectangular voltage to the horizontal coil.

Most vertical deflection coils have higher resistance, and a rectangular applied voltage would produce a current wave containing too much curvature. A sawtooth component must be added to the applied voltage, as indicated by the dashed curve in Figure 3B, to compensate for the high resistance of the vertical coil. Thus, a trapezoidal voltage is applied across the vertical coil to produce linear sawtooth current and vertical sweep.

EFFECT OF INDUCTANCE AND STRAY CAPACITANCE

In Figure 3, during the time that the applied voltage E_A is positive, either constant or rising, it produces a slow, steady rise of deflection-coil current I. To make the current fall quickly, E_A contains a large amplitude negative pulse at the end of each cycle. This pulse produces the necessary rapid change of current in the deflection coil.

As with any inductor, the deflection coil has a certain amount of distributed capacitance between its windings. Also, the circuit connections and components have stray capacitance. Together, these capacitances are across the coil, as indicated by the dashed-line capacitor C in Figure 4. As shown, capacitance C and the coil inductance L form a parallel LC circuit to which the rectangular or trapezoidal voltage E_A is applied.

When the negative pulse of E_A arrives, the resulting rapid change of coil current excites this LC circuit into oscillation. That is, a circulating current is set up in the LC tank circuit, with an oscillation frequency determined by the inductance L and capacitance C. Unless these oscillations are damped in some manner, the inductor current has the wave-form of Figure 5, instead of that of Figure 3C or D. An oscillating current in the deflection coil causes corresponding movements of the electron beam in the picture tube. The result on the image is a series of strips of the picture folded back over one another. If the oscillation is in the vertical coil, the strips are horizontal and at the top of the screen. In the case of oscillation in the horizontal coil, the strips are vertical and on the left side of the screen. The effect is called "foldover".

As shown in Figure 5, the oscillating current in the deflection coil LC circuit has the form of a damped sine wave. Part of the first cycle of this sine wave causes the current change needed in the coil to provide the proper return movement of the beam, from right to left or bottom to top of the screen. To be completed within the blanking intervals, the vertical retrace motion of the beam must not take more than about 570 microseconds, and the horizontal retrace motion not more than about 8 microseconds. Therefore, as indicated in Figure 5, the coil current must change from maximum in one direction to maximum in the other direction within the retrace time T_r of either 570 or 8 microseconds, as the case may be.

In the deflection coil, the rate of current change during retrace depends upon the resonant frequency of the LC circuit, Figure 4. As mentioned, this frequency is determined by the values of L and distributed C. Therefore, with a lower oscillation frequency for the long retrace time of 570 microseconds, the vertical deflection coil circuit can have larger values of L and C than the horizontal coil circuit which must oscillate at a relatively high frequency due to the short retrace time of 8 microseconds.

The deflection angle θ is directly proportional to the deflection coil flux density. In turn, the flux density is directly proportional to the ampere turns NI. Therefore, to obtain a large deflection without excessive plate current in the deflection circuit amplifier tube, it is desirable to employ a large number of turns in the deflection coils. However, the more turns in the coil, the greater its inductance and distributed capacitance. As explained above, the larger the values of L and C in the deflection coil circuit, the lower the frequency of the oscillations produced by the negative pulse of E_A. Consequently, the retrace time T_r limits the maximum L and C values and therefore the number of turns in the respective vertical and horizontal coils.

THE DEFLECTION AMPLIFIER

The deflection or sweep amplifier increases the level of the output voltage generated by the sweep oscillator, and supplies this amplified voltage usually through a step-down transformer to the deflection coil. The amplifier output voltage is an inverted replica of its input voltage, but increased in magnitude. Briefly then, the deflection amplifier provides a voltage of the proper wave-form to produce sawtooth current in the deflection coil.

A simplified deflection amplifier and coil circuit is given in Figure 6A. The voltage E_{in} is amplified by the tube action, and becomes E_b at the plate of V_1. In

Figure 6B, the plate resistance of V_1 and the a-c resistance of the deflection coil are combined and represented as resistor R, and the coil inductance as inductor L. The plate voltage E_b produces sawtooth current in the series RL circuit. Furthermore, the current in a resistor has the same wave-form as the voltage applied to it, while a rectangular voltage produces sawtooth current in an inductor. Since the circuit of Figure 6 consists of both resistance and inductance, the voltage E_{IN} applied to the V_1 grid must contain both sawtooth and rectangular components to produce sawtooth current in the circuit. Thus, as generated by the sweep oscillator, E_{IN} has the trapezoidal wave-form of Figure 6C. An earlier lesson explained the method of producing the trapezoid wave, which is a combination of sawtooth and rectangular voltages.

For easier viewing, the front of this cabinet is tilted forward to minimize glare by reflecting downward the light striking it from various room lighting sources.

Courtesy Trav-Ler Radio Corp.

The Vertical Amplifier

Because the standard aspect ratio of the television picture is 4:3, horizontal to vertical, a given deflection yoke provides a vertical deflection angle which is equal to only ¾ of the horizontal angle. For example, in the case of the typical yoke mentioned earlier which had a horizontal deflection angle of 70°, the corresponding vertical deflection angle is $\frac{3}{4} \times 70^\circ = 52.5^\circ$. Substituting this value for θ, along with .0635 meter for g, .089 meter for l, and 16,000 volts for E_A in equation (1), the ampere turns required for the vertical coil in this yoke are:

$$NI = \frac{.047 \times 52.5 \times .0635 \times \sqrt{16,000}}{.089}$$

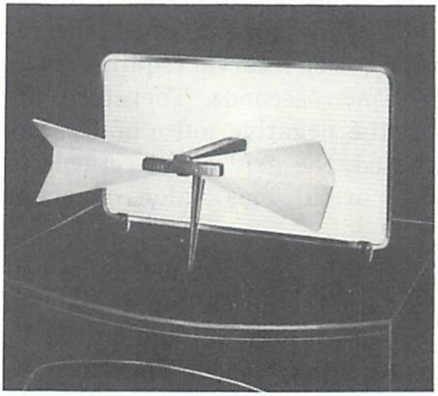
$= 222$ **ampere turns peak to peak approximately.**

If the vertical coil contains 850 turns, the 52.5° deflection angle requires a current of $222 \div 850 = .261$ ampere, or 261 ma peak to peak. While the deflection coil requires this large current, very little power is needed. Therefore, it is not economical to employ a vertical output stage with large power capabilities. In practice, a single tube voltage amplifier is used, with its plate circuit coupled to the deflection coil by means of a transformer with step-down turns ratio, primary to secondary.

A typical vertical amplifier circuit arrangement is shown in Figure 7. The output transformer T_1 is constructed like an audio transformer, and has a turns ratio ranging from 5:1 to 50:1. As you may recall, a step-down turns ratio results in current step up, primary to secondary. The primary current required is equal to the secondary current divided by the step up factor. For example, assume a turns ratio of 15:1, and a required secondary current of 166 ma. This current will be produced by a primary current of only 166÷15, or 11.07 ma. This current can be handled by the vertical output tube types such as the 12BH7.

As indicated in Figure 7, inductors L_1 and L_2 represent the vertical deflection coils. At the beginning of the flyback portion of the cycle, the sudden reversal of current would excite the coil LC circuit into oscillation if the coils were not damped. The fall of coil current induces an emf across the coils which tends to maintain the current. This induced emf is applied to the secondary of T_1, and thus coupled back to the plate circuit of V_1. Since the T_1 winding connected to the deflection coils has few turns compared with the winding in the V_1 plate circuit, the transformer acts as a voltage step-up transformer in the case of energy coupled in the direction from the coils to the output tube.

For example, suppose the rapid fall of current induces a peak voltage of 75 volts across L_1 and L_2 in the circuit of Figure 7. Applied to the secondary winding of T_1, this voltage is stepped up by the 15:1 turns ratio to a value of 15×75 or 1125 volts. Assume this voltage appears across the primary of T_1, and its polarity is positive toward the plate of V_1. If the B+ voltage is 350 volts, and the bias across R_2 and R_3 is 20 volts, the total difference of potential between the plate and cathode of V_1 is $1125 + 350 - 20 = 1455$ volts. This maximum value is present during the beginning of the flyback portion of the cycle only, but the tube must be con-



Designed for uhf reception, this indoor type antenna may be placed on top of the receiver cabinet.

Courtesy Channel Master Corp.

structed to withstand the pulse. The 12BH7, for example, has a rated "peak positive pulse plate voltage" of 1500 volts.

As shown in Figure 7, the voltage E_{IN} applied to the V_1 grid has a trapezoidal wave-form. The negative pulses of E_{IN} drive the grid nearly to cutoff, and thus limit the plate current during the instant when the plate voltage is maximum due to the positive pulse applied to it from T_1. However, the negative pulse of E_{IN} is only about 100 microseconds in duration, while, as explained, the return sweep interval requires about 570 microseconds. Therefore, after the negative pulse of E_{IN} has passed, the grid of V_1 returns to its normal bias value of about −20 volts.

At this time, the deflection coil current is still falling rapidly to produce a high voltage on the V_1 plate as explained. Therefore V_1 conducts heavily during the remainder of the return trace interval. #4 By conducting heavily in this manner, V_1 acts as a low resistance load on the deflection coils to prevent oscillations. Thus, the damping of the vertical deflection coil LC circuit is accomplished by operating the output amplifier tube so that it conducts during the flyback portion of the sawtooth cycle.

In addition to "stepping up" the sawtooth current, from the low value in the output tube plate circuit to the high value required by the deflection coils, the output transformer matches the impedance of the coils to the plate impedance of the tube. The impedance ratio is equal to the turns ratio squared. Therefore, the primary of T_1 presents to the V_1 plate an inductance equal to the deflection coil inductance multiplied by the square of the turns ratio of the transformer. Thus, with the turns ratio of 15 assumed in the example above, and a deflection coil inductance of 40 millihenrys, an inductance of $.04 \times 15^2$ or 9 henrys is presented to the amplifier tube plate.

In any transformer, the coupling between windings always is slightly less than unity. We may consider the total inductance of each winding as made up of two parts: a "coupling inductance" which has unity coupling with the other winding, and a "leakage inductance" which has no coupling at all with the other winding.

In the output transformer, the leakage inductance increases the tendency for oscillations in the deflection coil circuit. For this reason, additional damping is employed by connecting resistors R_4 and R_5 across the deflection coils.

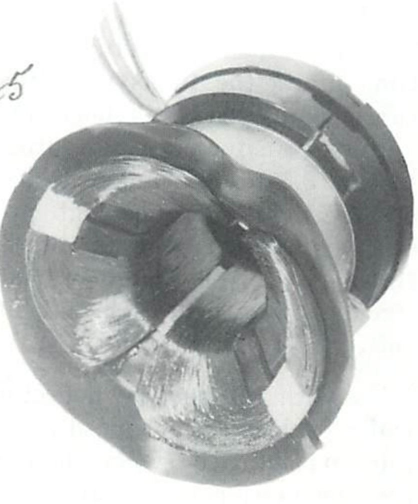
During the trace period of the cycle, the plate current of V_1 should rise at a constant rate to provide a linear sawtooth current in the deflection coils as shown in Figure 3C. If the rate of current rise decreases with time, the electron beam in the picture tube moves downward more slowly as it approaches the bottom of the raster. As the horizontal lines are still being produced at the same rate, they are produced closer together, and may overlap near the bottom of the screen. The result on the picture is that objects near the bottom of the screen have less than normal dimensions, in the vertical direction. For example, the image of a person is reproduced such that the upper part of his body is normal, but his legs are very short. This type of distortion is called vertical nonlinearity or compression.

In the circuit of Figure 7, the cathode bias resistor R_3 is variable to permit linearity correction. The slider shorts the lower portion of this resistor so that only the upper part and R_2 are in the cathode circuit. Moving the R_3 slider downward increases the resistance in the cathode circuit, and thus increases the bias voltage between cathode and ground. With increased bias, the tube operates nearer cutoff. As shown in Figure 8, when the applied voltage E_{IN} contains curvature, the tube can be operated at a point such that the I_b-E_c curvature corrects for the curvature in E_c to provide a linear sawtooth plate current. Since the cathode bias determines the operating point of the tube, R_3 is called the **linearity control.**

The Horizontal Amplifier

As explained earlier, the horizontal deflection coil in a typical deflection yoke must provide an mmf of approximately 295 ampere turns for a deflection angle of 70°. Also, the deflection coils are limited with regard to the number of turns to permit a sufficiently high resonant frequency in the coil LC circuit. Thus, to produce the required flux density for a 70° deflection, a coil containing 350 turns must carry a current of 295÷350 or .843 ampere, or 843 ma peak to peak. Again,

#5



A yoke designed to provide a deflection angle of 90°. The windings visible here are those of the horizontal coils.

Courtesy Thordarson-Meissner

this deflection coil current is much too great to be carried by the amplifier tube without considerable waste of power. As in the vertical circuit, an output coupling transformer is employed which has a step-down turns ratio, primary to secondary.

However, all such transformers have a certain amount of leakage inductance and stray capacitance depending upon the number of turns in the windings and the construction. These inductance and capacitance values add to the L and C values of the deflection coil to reduce its resonant frequency. Because of the shorter return trace time in horizontal deflection, the horizontal coil must produce higher frequency oscillations, and therefore must contain smaller LC values than the vertical coil. Thus, the return trace time limits the turns ratio that can be employed in the horizontal output transformer to approximately 3.5 to 1, primary to secondary. This arrangement provides a current step up of 3.5 times, from the amplifier plate circuit to the deflection coil circuit.

As with the vertical deflection coil, a back emf is produced across the horizontal coil when the current changes rapidly during the retrace interval. Usually, the horizontal coil inductance is from about 1/6 to 1/2 that of the vertical coil. For an example, assume the horizontal coil to have 1/4 the vertical coil inductance in a yoke in which the back emf produced across the vertical coil is 75 volts peak during retrace. If the current changed at the same rate in the horizontal coil, the back emf produced would be only $\frac{1}{4}$ of 75, or 18.75 volts peak.

However, the vertical retrace can take as long as 500 microseconds or more, while the horizontal retrace time is only 8 microseconds or less. Therefore, the current changes 500 ÷ 8, or about 62.5 times as rapidly in the horizontal coil as in the vertical coil. In any inductor, the back emf produced is directly proportional to the speed at which the flux lines cut the coil. In turn, the speed of cutting is determined by the rate of current change. Thus, in the above yoke, the back emf produced across the horizontal deflection coil during retrace is 18.75 ×62.5 or 1172, or approximately 1200 volts.

In the same manner explained for the circuit of Figure 7, the horizontal deflection coils apply the back emf to the secondary of the output transformer. Because there are 3.5 turns in the primary for each turn in the secondary, this 1200 volts is stepped up to at least 3.5×1200 or 4200 volts by the transformer action, and this stepped up voltage appears across the primary. In practice, the leakage inductance of the horizontal output transformer and LC resonance actions in the transformer increase the voltage step-up ratio by a factor of about 1.43.

Therefore, with 1200 volts applied to the secondary by the deflection coil, the voltage applied by the primary to the plate of the horizontal amplifier tube is approximately 4200×1.43, which is roughly 6000 volts. This voltage is added in series with the B+ voltage of about 400 volts, so that the total voltage applied to the amplifier plate is about 6400 volts. Both the tube and the output transformer must be constructed to withstand this high voltage pulse. For example, one tube type designed for this application, the 6BG6G, has a peak positive pulse plate voltage rating of 6600 volts.

To prevent the sweep distortions caused by oscillations in the LC circuit of the horizontal deflection coil, this coil must be damped in some manner. As explained, in the vertical circuit, damping is accomplished by permitting the amplifier tube to conduct during retrace, and thus load the deflection coil to the extent that oscillations cannot occur. However, in the case of the horizontal circuit, this method would be too wasteful of power because of the large plate current which would be produced by the 6000 volt pulses applied by the transformer primary to the plate of the tube. Therefore, the horizontal amplifier tube is held cut off during the entire retrace interval.

Designed to match the many styles of home furnishings, television receiver cabinets may be selected to harmonize with their surroundings in any room.

Courtesy Pacific Mercury TV Mfg. Corp.

A damping method is shunting the deflection coils with resistors as shown in Figure 7. In the vertical circuit, resistors, R_4 and R_5 have values of about 600 ohms each, for a total of about 1200 ohms across the two coils. During sweep, the voltage across the coils is about 0.5 volt which produces a current of 0.5÷1200 or approximately .0004 ampere (0.4 milliampere) in the resistors. As explained, the main damping is provided by the current in the vertical amplifier tube.

However, to damp the horizontal coils with shunt resistors, with the amplifier tube cut off, the total resistance across the coils would have to be less than about 1000 ohms. During trace, the voltage across the horizontal coils is about 100 volts, and the damping resistors would carry a current of 100 ÷ 1000 or 0.1 ampere. During retrace, the 1200 volts induced across the coil would produce a current pulse of 1200 ÷ 1000 or 1.2 amperes in the damping resistors. The power thus dissipated would have to be replaced by the horizontal amplifier during the trace period. Thus, it is desirable that the damping resistors conduct during the trace period, but not during retrace.

In practice, to connect the "damping circuit" across the coils during trace and switch it out during retrace, a system of electronic damping is employed. The basic method consists of replacing the shunt resistors with a diode tube as shown in Figure 9.

With respect to circuit voltage polarities, damping diode V_2 is connected so that the high voltage pulse across L_1 during retrace makes the diode plate negative with respect to the cathode. Therefore, V_2 does not conduct during retrace, but does conduct to damp the coil when the upper end of L_1 is positive during the trace period.

The simple arrangement of Figure 9 has the disadvantage that the damping tube conducts for the entire trace period, long after it has served its purpose, and the need for damping has passed. #7 Also, the resistance of the diode is low compared with the reactance of the deflection coils. Therefore, V_2 carries a large part of the current provided by T_1.

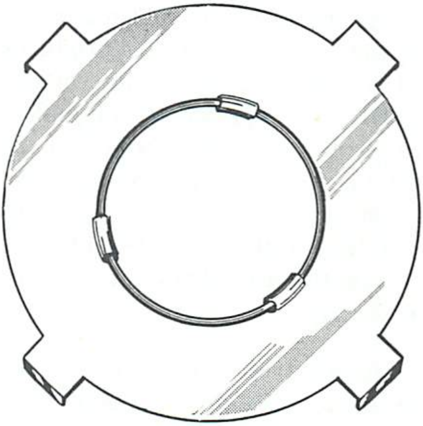
The current carried by V_2 during the latter part of the sweep cycle is wasted, since it does not pass through L_1 to produce the deflection field. To fill the needs of both L_1 and V_2, amplifier tube V_1 must provide more current to the primary of T_1 than it would if V_2 conducted only when it is needed during the first portion of the forward trace.

To meet this requirement and thus increase the efficiency of the damping circuit, the bias arrangement of Figure 10 is used. V_2 current charges C_1 to the polarity indicated. The voltage E_{C_1} biases the cathode of V_2 positive. As a result, only during approximately the first half of the trace period does V_2 conduct heavily, to achieve the desired damping action. R_1 permits C_1 to discharge slightly during the portion of the cycle when V_2 is not conducting.

With the arrangement of Figure 10, not only is it unnecessary for the damping tube to conduct during the last half of the trace period, it is also unnecessary for the horizontal amplifier tube to conduct during the first half of this period. V_1 is operated so that it is cut off during the retrace interval as well as approximately the first half of the forward trace. During the last half of the trace, V_1 conducts to supply energy through T_1 to L_1. This energy is not dissipated in L_1, but instead, returned to the circuit to provide the deflection current for the first half of the trace. These actions to be described are illustrated in Figures 11 and 12.

In Figure 11, curve E_g shows the wave-form of the voltage applied to the grid of V_1. The horizontal dashed line represents the cutoff level, below which the tube is nonconductive. When the grid is above the cutoff level, between points 1 and 2, plate current is produced in the form shown by curve I_b. Carried by the primary of T_1, the rising current I_b produces a changing magnetic field which cuts the turns of the secondary to induce the constant positive voltage E_L. Applied to the deflection coil L_1, E_L produces the steadily rising current I_L. During this time, point 1 to point 2, E_L makes the plate of V_2 positive, but the voltage across C_1 is greater than E_L, therefore the cathode of V_2 is more positive than the plate, and the damper tube current I_D is zero.

Curve I_L in Figure 11 indicates that the deflection coil current is an alternating current with saw-tooth wave-form. At points where the curve crosses the zero axis, the deflection current is zero and the spot is at the middle of the screen. Where the curve is above the line, the current is in the direction which makes the spot deflect to the right of center. The spot is deflected to the left of center when the current is in the other direction, indicated by the curve below the zero line.



Used for centering the beam, this permanent magnet device, the "beamadjuster", fits around the picture tube neck, between the focus coil and deflection yoke.

Courtesy Perfection Electric Co.

The middle of the forward trace period is represented by point 1 in Figure 11. At this instant, the spot is at the center of the screen, and moving toward the right. The E_g curve shows that V_1 is just coming out of cutoff. At this instant, the positive swinging grid increases plate current I_b until it reaches a maximum at point 2. During the period from point 1 to point 2, the conditions in the deflection coil circuit are indicated in Figure 12A. The plate current in the primary of T_1 produces across the secondary the voltage E_s which is applied to the deflection coil L_1. The polarity of E_s produces current in the direction of the arrows. Here, the dashed-line capacitor C_s represents the distributed and stray capacitance across L_1.

The electron flow charges C_s to the same voltage and polarity as E_L which also is the back emf produced across L_1 by the expanding deflection field. Since E_L is equal to the applied voltage E_s, both are represented between points 1 and 2 by curve E_L in Figure 11. Also, between these points in Figure 11, curve I_L rises in the positive direction to indicate the increasing deflection coil current in the counterclockwise direction in Figure 12A.

At point 2, Figure 11, E_g swings highly negative and cuts off plate current I_b. With no current in the primary, there is no voltage induced in the secondary of the output transformer. Current I_L begins to fall rapidly toward zero. The rapidly collapsing deflection field cuts L_1 to induce a large emf in this coil. The induced emf is in the direction to maintain the current, and therefore has the polarity indicated in Figure 12B. As the curved arrows show, the induced voltage E_L produces electron flow in the L_1C_s circuit. This electron flow quickly discharges C_s and then charges it in the opposite direction to that indicated.

When I_L reaches zero, point 3 in Figure 11, the capacitance C_s is charged to a high voltage with the polarity indicated in Figure 12C. This high voltage E_{C_s} is also across L_1, and is indicated in Figure 11 by the negative peak (point 3) of the E_L curve. At this instant, the spot has been moved from the right side back to the middle of the screen, all currents are zero, and there is no deflection field.

Between points 3 and 4 in Figure 11, C_s discharges through L_1, to produce a rising current in the direction indicated by the arrows in Figure 12D opposite to that shown in Figure 12A. Represented in Figure 11 by curve I_L between points 3 and 4, this current produces a rising magnetic flux which deflects the spot from the center to the left side of the screen.

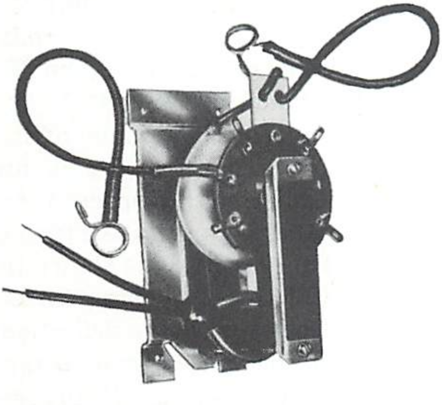
Thus, between points 2 and 4, the change of deflection coil current I_L from maximum in one direction to zero, and then to maximum in the other direction produces a like change in the deflection field. This change in deflecting flux moves the spot quickly from the right to the left side of the screen. Figures 12B, C, and D show that the upper end of L_1 is negative during this interval, and curve E_L in Figure 11 also shows that this voltage is negative. This negative voltage is applied to the plate of V_2, and thus prevents conduction of the damper tube during flyback.

When C_s becomes discharged, I_L begins to decrease, point 4 in Figure 11. The deflection field begins to collapse, cutting L_1 to induce an emf in a direction to maintain the current, as shown in Figure 12E. The resulting electron flow begins to charge C_s to the polarity indicated. This action is the beginning of the second half of the oscillation cycle, the frequency of which is determined by values of L_1 and C_s.

However, as soon as the voltage across C_s slightly exceeds that across C_1, the plate of V_2 is made more positive than the cathode, and the damper tube begins to conduct. Thus, due to the induced voltage E_L, electrons flow from the lower terminal of L_1 into the lower plate of C_1, and from the upper plate of this capacitor, through V_2 to the upper terminal of L_1. Indicated by the arrows in the clockwise direction in Figure 12E, this current dies down at a rate determined by the time constant L_1/R_2, where R_2 is the resistance of V_2. The decrease of deflection coil and damper tube current is shown by curves I_L and I_D between points 4 and 5 in Figure 11.

As the capacitance of C_1 is much greater than that of C_s, the voltage rises slowly across C_1. To simplify the explanation of Figure 12, R_1 of Figure 10 is omitted, as its only purpose is to permit C_1 to discharge slightly when V_2 is not conducting. When C_1 becomes charged to the value of E_L and E_{Cs}, the plate of V_2 is no longer positive with respect to the cathode, and damper tube current ceases. This condition is shown in Figure 12F. Again, current in L_1 is zero. However, as the deflection current I_L decreases from maximum at point 4, Figure 11, to zero at point 5, it produces a linear fall of flux which moves the spot from the left side to the center of the picture tube screen. Thus, by conducting as explained, damper tube V_2 provides the current change needed in L_1 to produce the first half of the forward trace. In Figure 11, point 5 completes the cycle of events begun at point 1.

In the actual deflection circuit, the damper tube does not stop conducting at the exact instant that the amplifier tube starts conducting as indicated by the somewhat simplified curves I_L and I_D of Figure 11. Actually, both of these tubes conduct more than half of the sweep time. That is, in Figure 10, V_1 begins to conduct before V_2 stops. This situation is illustrated in Figure 13 which shows the curve of the deflection coil current in greater detail in the region where I_L changes direction as the spot crosses the center of the screen during its left to right sweep.



A horizontal output transformer. Special insulation and construction is provided to withstand the high voltages produced across the windings of these units.
Courtesy Chicago Standard Transformer Corp.

At the beginning of this sweep period in Figure 13, I_L is decreasing from its maximum value in the negative direction. At this time the emf across L_1 is producing currents I_L and I_D in the path indicated by the arrows in Figure 12E. That is, I_L and I_D are the same current, and therefore equal. At point 1 in Figure 13, amplifier tube V_1 (Figure 10) begins to conduct to produce a voltage E_s across the secondary of T_1. E_s causes the rising current I_s, Figure 13.

Figure 14A illustrates the circuit conditions during the time interval between points 1 and 2 in Figure 13. At this time, the damper tube current I_D consists of the two components I_s and I_L. Produced by E_s, current I_s is carried by V_2 and the secondary of T_1 as indicated, while I_L is carried by V_2 and L_1, due to the induced voltage E_L. Although I_s is rising, I_L is falling at the faster rate indicated by the dashed portion of the curve in Figure 13. Due to these changes in I_s and I_L, the damper current I_D continues to decrease, but not as rapidly as it did before I_s began.

At point 2, I_L has fallen to zero, and I_D is equal to I_s. As shown in Figure 14B, V_2 current is due entirely to E_s, and continues to charge C_1. As this capacitor becomes more charged, its voltage opposes electron flow in the V_2 branch of the circuit. Thus, damper tube current continues to decrease as indicated by the I_D curve in Figure 13. At the same time, I_s continues to increase, the excess electrons flowing through L_1

to produce the current conditions of Figure 14C. Finally, when the voltage across C_1 equals the applied voltage, V_2 stops conducting, point 3, Figure 13. For the remainder of the trace period; all of I_s is carried by L_1 to form the deflection current I_L as indicated by the arrows of Figure 12A.

THE BOOST VOLTAGE CIRCUIT

As mentioned, in the circuit of Figure 10, resistor R_1 permits C_1 to discharge to some extent during the time that the damping tube is not conducting. This discharge of C_1 is necessary to lower the V_2 cathode voltage to a level which permits the tube to conduct during the trace period as explained.

However, the power thus dissipated in R_1 represents wasted energy which must be resupplied by the receiver power supply. To recapture the power which would be otherwise dissipated in R_1, this resistor is replaced by the plate circuit of V_1 in a circuit arrangement shown in Figure 15. Here, the plate of V_1 connects through the T_1 primary to the positive plate of C_1, the negative plate of which connects to B+. These connections place the voltage across C_1 in series with the B supply voltage, so that the V_1 plate receives a higher voltage than is available at B+. The arrangement is called a "booster circuit", and the voltage applied to the plate of V_1 is known as the **boost voltage.**

For example, if the B supply provides 350 volts and the average voltage across C_1 is 50 volts, the V_1 plate is supplied a boost voltage of $350 + 50$ or 400 volts. The boost circuit arrangement in no way interferes with the normal action of the deflection circuit. That is, sawtooth alternating current is produced in L_1 by the combined action of V_1 and V_2 in the manner explained for Figures 11, 12, 13, and 14. In addition to the plate of the horizontal amplifier tube, in many receivers, the boost voltage is supplied to electrodes of other tubes, such as the plate of the vertical output amplifier and the screen grid of the picture tube.

A more complete schematic of a horizontal output circuit is shown in Figure 16. The pentode amplifier tube V_1 has its plate connected to a tap on the primary winding of transformer T_1 through which it couples the energy to drive the deflection coils L_1 and L_2. Damping diode V_2 is connected to provide a booster circuit much like that explained for Figure 15. V_2 current causes both C_1 and C_2 to charge to the indicated polarity. C_2, L_3, and C_1 form a pi-type network which provides the desired boost voltage to the plate

#8

of V_1. The two sides of the horizontal deflection coil are represented by L_1 and L_2. Because these coils are unbalanced, capacitor C_4 is included to balance the capacitance of both sides of the winding with respect to ground.

If the picture tube face is curved, a linear sawtooth current in the deflection coils causes the spot to move equal distances on the screen in equal intervals of time. However, with the commonly used flat face screens, the center of the screen is nearer to the deflection yoke than the sides. In this case when the spot is near the sides of the screen, it moves a greater distance in the time required for the beam to deflect through a given angle than when the spot is near the center of the screen.

To obtain uniform speed of the spot across the entire screen of a flat face picture tube, the beam must deflect more rapidly when it is near the sides of the screen. This deflection requires that the deflection coils receive a slightly non-linear sawtooth current. The current should rise somewhat more steeply near the beginning and near the end of its forward sweep period. To obtain a sawtooth current of this type in the deflection coils, the C_1-L_3-C_2 network supplies the V_1 plate with a boost voltage. Called the **linearity control,** variable inductor L_3 can be adjusted to obtain the proper rate of change of the voltage across the C_2, L_3 and C_1 network. Added to the voltage across V_2, this change of voltage provides linear operation.

In the horizontal deflection circuit, the output amplifier tube is cut off during retrace and the first part of the forward trace period. As explained, the deflection action during this time is due to energy which had been stored in the magnetic field about the deflection coils. Thus, for approximately the first half of the trace, the deflection coil current is carried by the damper tube. As a result, the amplifier circuit supplies only about six-tenths of the current required by the deflection coils.

Also, it has been mentioned that, during flyback, the deflection coil produces a negative pulse of voltage, E_L in Figure 11, and that this pulse is transformed by the output transformer to a positive pulse of 6000 volts or more and applied by the primary to the plate of the amplifier tube. However, in the circuit of Figure 16, the T_1 primary is a form of auto-transformer, when viewed from the V_1 plate circuit.

When the flyback action produces the positive pulse at the V_1 plate, it also induces a positive pulse at the upper terminal of the T_1 primary. At this latter point, the peak value of the pulse lies in the range of voltages for the anodes of picture tubes. This range is from 12,000 to 22,000 volts. As indicated by the upper dashed lines in Figure 16, a rectifier and capacitor are connected in series between the upper terminal of the T_1 primary and ground. The voltage pulses produce rectified current which charges C_5 to the peak voltage of the pulses. Described in detail in the lesson on high voltage supplies, this arrangement provides the desired high anode voltage for the picture tube.

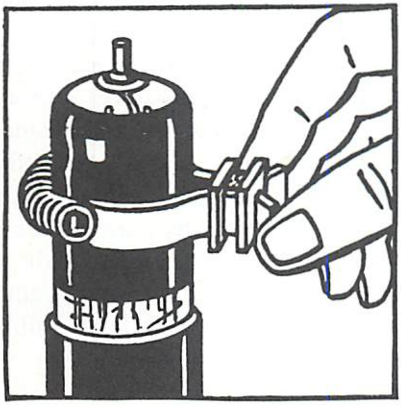
TYPICAL OUTPUT CIRCUITS

To illustrate typical sweep output circuits employed in commercial equipment, the vertical and horizontal deflection circuits used in the Mattison Model 630DSM television receiver are shown in Figure 17. At the upper left in the Figure, transformer T_1, triode V_1 and the associated resistors and capacitors form a blocking oscillator type sweep generator. The trapezoidal voltage is produced across C_2 and R_8, and coupled by C_5 to the grid of the output amplifier tube V_2. Operated as a triode, V_2 applies the amplifier trapezoidal voltage to transformer T_2, the output of which produces sawtooth current in vertical deflection coils L_1 and L_2.

Resistor R_2 permits a small range of adjustment of the sweep frequency, while in the V_1 plate circuit, height control R_6 determines the voltage to which C_2 charges while V_1 is cut off. In the V_2 cathode circuit, linearity control R_{11} sets the operating point of the amplifier tube to provide the proper sweep voltage waveform. To improve linearity, R_8 is connected to the cathode of V_2 so that R_{10} and R_{11} carry the C_2 charging current. This rising current produces a small voltage across these resistors, and this causes the V_2 cathode voltage to increase slightly to cancel nonlinearity in the positive rise of grid voltage. Also, due to the connection of R_8 to the V_2 cathode, the C_2 discharge current is carried by R_{10} and R_{11}, and causes the V_2 cathode voltage to fall to a low value to allow heavy conduction of the amplifier tube during retrace.

To position the entire raster at the proper place, vertically, on the screen, a small direct voltage is inserted in series with the trapezoidal voltage in the deflection coil circuit. This direct voltage is obtained from R_{14}, the vertical centering control. Resistors R_{13} and R_{14} form a voltage divider between the +235 and +225 volt output terminals of the B supply. By moving the slider on R_{14} to the left or right of the tap, it is possible to make the right end of L_2 either positive or negative with respect to the left end of L_1. In this way, a direct current passes through the deflection coils to produce a direct component of magnetic field in the direction needed to properly position the raster.

At the lower left, the horizontal sweep generator consists of the sine wave oscillator V_3 and discharge tube V_4. Horizontal sweep frequency adjustments are made by means of hold control R_{19}. The trapezoidal voltage is formed across C_{14} and R_{25}, and applied to the capacitance voltage divider $C_{15}C_{16}$. The voltage across C_{16} is coupled through parasitic suppressor resistor R_{27} to the grid of output tube V_5. Called the drive control, C_{16} is adjusted to provide the proper magnitude of grid driving voltage to V_5.



Designed for electrostatically focused picture tubes, the "kine-center" is a permanent magnet focusing device which mounts just back of the deflection yoke.

Courtesy Perfection Electric Co.

For proper impedance match, horizontal deflection coil L_3 connects to a tap on the secondary of output transformer T_3. The path of the deflection current is from this tap, through L_3 and L_4 and width coil L_5 to the slider on horizontal centering control R_{13}, the right hand portion of R_{13}, capacitors C_8 and C_7, to the lower terminal of the T_3 secondary, and up through this winding to the tap. The deflection magnitude is determined by the amplitude of this current which can be varied by adjusting width coil L_5.

The damper tube circuit connects across the entire secondary winding of T_3. Here, V_6 current charges C_{20} to the indicated polarity. In series with the +225 volt output of the B supply, the voltage across C_{20} provides the boost voltage. This boost voltage is applied through the right hand portion of L_7, fuse F_1, and a portion of the T_3 primary to the plate of V_5. This same voltage also is applied through R_7, R_6, and R_5 to the trapezoidal forming circuit in the vertical sweep oscillator, and through the primary of T_1 to the plate of V_1.

To provide a direct current in the horizontal deflection coils for centering purposes, the lower terminal of L_4 connects through L_5 to the slider on R_{13}, while the upper terminal of L_3 connects through the T_3 secondary winding to the +225 volt B supply terminal.

As a second sweep output circuit example, Figure 18 shows the vertical and horizontal deflection circuits employed in the Admiral 18SX4BZ television receiver chassis. Here, tubes V_1 and V_2 are the vertical blocking oscillator and output amplifier, respectively; V_3 and V_4 the horizontal multivibrator, V_5 is the horizontal output amplifier and V_6 the damper tube.

From the three section integrating network, vertical sync pulses are coupled through C_4 and the secondary of blocking oscillator transformer T_1 to the grid of triode V_1. In operation, variable resistor R_5 permits adjustment of the oscillator frequency. The trapezoidal voltage is produced across R_6, C_6, and C_7, and coupled through C_8 to the grid of the output tube V_2.

In the plate circuit of V_2, transformer T_2 consists of a single winding in which the upper section is the primary and the lower section the secondary. The vertical deflection coils are connected across the T_2 secondary. To assure that the spot is blanked during vertical retrace, the vertical output circuit applies negative voltage pulses (spikes) to the grid of the picture tube. As indicated, these pulses are obtained from the network connected between the deflection coils and ground, and are of the required amplitude and polarity to prevent a screen trace.

The frequency of the horizontal multivibrator can be varied by horizontal lock coil L_1, and is maintained by means of a direct voltage applied from the horizontal control circuit to the grid of V_3. Produced across C_{15} and R_{20}, the trapezoidal voltage is applied to a voltage divider consisting of drive control C_{16} and resistor R_{21}. Increasing the capacitance of C_{16} decreases its reactance and allows a greater portion of the sweep voltage to appear across R_{21} and thus be coupled through parasitic suppressor resistor R_{22} to the grid of the output tube.

Horizontal output transformer T_3 is a single winding containing two taps, one of which connects to the plate of V_5, and the other to the deflection coils and damper tube cathode. Like T_2, T_3 is an autotransformer. The primary is that part of the winding between the upper tap and lower end, while the section between the lower tap and lower end forms the secondary.

This transformer design permits construction which minimizes stray capacitance and leakage inductance. With lower L and C values in the transformer, more turns can be employed in the deflection coils without making the oscillation frequency of the coil LC circuit too low. With more turns in the deflection coils, the required deflection flux density is obtained with a smaller current. With their greater inductance, the deflection coils employed in the circuit of Figure 18 are known as high impedance coils, while those used with the "isolated secondary" transformers of Figure 17 are called low impedance deflection coils. Since a given deflection angle is provided with less deflection current in the output circuits of Figure 18, the circuit arrangement is known as the direct drive HIGH-EFFICIENCY SYSTEM.

#10 To match the impedance of the deflection coils to the plate of the amplifier tube V_5, Figure 18, the secondary section of T_3 has many more turns than are employed in the output transformer secondary in the case of low impedance deflection coils. As a result, higher voltages are produced across the transformer and deflection coils during both trace and retrace. With the higher deflection circuit voltages present, the boost voltage can be made approximately double the value of the voltage available from the receiver B supply.

In the circuit of Figure 18, the path of the deflection coil alternating current includes the lower section of T_3, the deflection coils, C_{21}, R_{26}, C_{22}, and C_{18}. Included in the Figure to show this path, capacitor C_{22} is the output filter capacitor of the B supply. C_{19} is added to the distributed capacitance of the coils to provide the total capacitance needed. From the junction between C_{21} and R_{26}, 15,750 cps pulses are taken to serve as a reference input signal to the horizontal control circuit. As mentioned, this circuit produces the control voltage applied to the grid of multivibrator tube (V_3-V_4). Described in another lesson, the control circuit compares the incoming horizontal sync pulses with the signal obtained from the horizontal output circuit to provide the required control voltage.

In the damper tube circuit, electrons flow from the cathode to the plate of V_6, to the lower plate of C_{18}, from the upper plate through the secondary section of T_3, and from the tap to the cathode of V_6. This current charges C_{18} to the polarity indicated. In series, the voltage across C_{18} and the B+ voltage form the boost voltage which is applied through T_3 to the plate of horizontal amplifier tube V_5.

The boost voltage is applied also through resistor R_{24} to the screen grid of the picture tube; through the primary section of T_2 to the plate of V_2 and through height control R_8, resistor R_7, and the primary of T_1 to the plate of V_1. Capacitor C_{10} stabilizes the V_2 cathode voltage, while C_9 and C_{10} together stabilize the boost voltage. Also, from the upper end of T_3, a high voltage pulse is applied to a rectifier circuit to provide the anode voltage for the picture tube. Across the horizontal deflection coils, C_{19} adds to the distributed capacitance to provide the proper impedance match. C_{20} balances the capacitances of the two coils to ground, while R_{25} adjusts the voltage phase relations to produce like currents in each coil.

SWEEP CIRCUIT TROUBLES

Working together, the vertical and horizontal sweep circuits produce the raster on the screen of the picture tube. To accomplish this purpose they supply sawtooth currents to the respective coils of the deflection yoke, and high voltage to the anode of the picture tube. To provide faithful picture reproduction, the produced raster must have the correct height and width, evenly spaced lines, and be free of foldover and other distortions. Any sweep circuit defect which alters the voltage applied to the deflection coils results in a change in the size, shape, or linearity of the raster. In addition, loss in synchronism can be caused by troubles in the sweep circuits, as well as in preceding sections which carry sync signals, video signals, or the picture signal carrier.

Examples of sweep circuit defects are changes in resistance of R_1, R_2, or R_3, Figure 18, or leakage in C_1, C_2 or C_3. Forming the integrating circuit, these resistors and capacitors build up 60 cps sync pulses of sufficient amplitude to control the vertical oscillator frequency. A defective component here can reduce the amplitude of the sync pulses to cause loss of vertical synchronism. The picture then slides or "rolls" vertically on the screen. The same symptom results when R_5 is misadjusted.

Shown here, the type 20GP4 is a typical picture tube. Any deflection circuit defect results in some type of distortion of the raster on the screen of the television picture tube.

Courtesy Allen B. DuMont Labs.

The free running frequency of the blocking oscillator is mainly determined by T_1, C_4, R_4, and R_5. Defects in any of these, or in V_1 or C_5, may make it impossible to stop the picture roll by adjusting R_5. A fairly good rule—if the hold control changes the speed of the vertical rolling on the screen by a considerable amount, or even reverses its direction, the vertical oscillator is working properly, but the sync pulses applied to it are too weak. If the hold control has little or no effect on the rolling speed, then it is likely the vertical oscillator circuit is defective.

In the case of the multivibrator type sweep oscillator, such as that in the horizontal circuit of Figure 18, every component in the circuit has some effect upon the oscillation frequency. Those that have the greatest effect, however, are C_{13} and R_{16} which couple the V_3 plate to the V_4 grid, and the tank circuit components, C_{14} and L_1. Loss of horizontal synchronism may cause a horizontal pulling effect on the picture, tearing of a few or several lines, production of multiple pictures, or complete break-up of the picture, depending upon the extent to which the oscillator is off frequency. These symptoms can be caused by an incorrect control voltage due to a defect in the horizontal control circuit, by misadjustment of L_1, or by a defect in a multivibrator circuit component. Considerable leakage in C_{13}, or change in R_{16} resistance, can make it impossible to return the multivibrator to the correct frequency by adjusting L_1.

The components in the oscillator output circuit and the amplifier stage determine the amplitude and shape of the trapezoidal voltage. A decrease in vertical or horizontal sweep voltage amplitude reduces the height or width, respectively, of the picture on the screen. In the V_1 plate circuit, Figure 18, misadjustment of R_8, increase in resistance of R_7 or R_8, or leakage in C_7 can prevent C_7 charging a sufficient amount while V_1 is cutoff. Leakage in C_6 reduces the magnitude of the negative spike of the trapezoid. These defects decrease the amplitude of the sweep voltage.

#9

In the vertical amplifier circuit, a defective amplifier tube V_2 or output transformer T_2 can be the cause of a reduced trapezoidal voltage applied to the deflection coils. Low sweep voltage amplitude results also, if the boost voltage applied to the plates of V_1 and V_2 is low due to a defect in the horizontal sweep circuit.

In the V_2 grid circuit, coupling capacitor C_8 can become leaky, or R_9 decrease in resistance, to produce a nonlinear voltage waveform at the grid of V_2. With this voltage applied to the vertical coils, the spot moves downward more and more slowly as it approaches the bottom of the screen. As a result, the scanning lines are bunched together at the bottom, and spread apart at the top, to produce vertical nonlinearity of the picture. The same general result is produced by misadjustment of the linearity control R_{10}, or a defect in C_9, C_{10}, R_{10}, or R_{11}.

Insufficient width may be caused by a defective horizontal oscillator or amplifier tube, or a defective blocking oscillator transformer. In the circuit of Figure 17, the discharge tube V_4, or its grid or plate circuit components may become defective to decrease the amplitude of the sweep voltage to reduce picture width, or distort the voltage wave-form to produce non-linearity. Excessive or decreased width can result from misadjustment of the horizontal drive control, C_{16} in Figures 17 and 18.

Other common causes of insufficient width are reduced B+voltage, increase in resistance of R_{23}, Figure 18, leakage or reduced capacitance in C_{17}, defective damping tube, V_6, output transformer T_3, or the capacitor C_{18} which is charged by the damping tube current to produce the boost voltage.

In Figure 17, linearity coil L_7 impairs both width and linearity when it becomes defective. Likewise, improper width and linearity result from a defect in width coil L_5.

It has been explained that the damping tube reduces unwanted oscillations in the horizontal deflection coils and transformer secondary circuit. However, in the T_3 primary circuit, Figure 17, there exists leakage inductance and stray capacitance upon which the damping tube has little effect. Therefore, one or more complete cycles of oscillation occur which drive the V_5 plate alternately highly positive and highly negative.

These plate voltage variations may cause the horizontal amplifier to operate as a Barkhausen oscillator for a brief interval. Electrons are attracted from the cathode of the tube by the positive screen grid, and travel toward the plate. However, in the intervals when the plate is negative, the electrons stop before reaching the plate, and begin moving back toward the cathode. As they near the cathode, they stop again and start toward the plate due to the attraction of the positive screen. These oscillations of bunches of electrons occur at very high frequencies, and cause radiation of h-f energy into the surrounding area.

Picked up by the receiver r-f stages, this energy modulates the signal, and results in the production of one or more vertical black bands near the left side of the picture tube screen.

As mentioned in connection with Figure 16, the high voltage required for the picture tube anode is obtained by rectifying the voltage across the primary of the horizontal output transformer. This and other high voltage supply systems form the subject of the next lesson.

APPENDIX A

The following explanations relate to the derivation of Equation (1) in the text. No attempt will be made to include all details. However, if the overall problems involving the construction of a deflection assembly are more understandable, these pages have served their purpose.

The deflecting force F, exerted on the electrons of the beam, depends upon the strengths of the interacting fields, while the charge on the electrons and their velocity determines the strength of the magnetic field around the beam. The strength of the magnetic deflecting field is determined by the design of the coil and the current in it at any instant.

The deflecting force is related to these factors as follows:

$$F = Bev \qquad \text{(I)}$$

where:

F = force in newtons (1 newton = 100,000 dynes)

B = flux density of deflecting field in webers (1 weber = 10^8 maxwells)

e = electron charge in coulombs

v = electron velocity in meters per second

In a magnetic circuit, the magnetic flux corresponds to the current in an electric circuit. The total flux of the deflecting field is represented by all of the flux lines in Figure 1 of the text, or all of the dots in Figure 2. However, the flux density, B in equation (I) above, designates the number of lines in a unit area. The number of unit areas covered by the deflecting field is calculated by multiplying the width of the coil by its length. Thus, the width w times the length l, Figure 2, gives us a total of wl unit areas. If the total flux is ϕ (Greek letter phi—pronounced fy) webers, then the flux in one unit area is the flux density:

$$B = \frac{\phi}{wl} \qquad \text{(II)}$$

where:

ϕ = the total number of flux lines in webers

w = deflection coil width in meters

l = deflection coil length in meters

APPENDIX A—(Cont'd)

Similar to an electric circuit, the total flux ϕ in a magnetic circuit is determined by the magnetomotive force applied and the reluctance of the path through which the flux passes. Written in the form of an Ohm's Law equation:

$$\phi = \frac{\text{mmf}}{R} \qquad \text{(III)}$$

where:

mmf = magnetomotive force in ampere turns

R = reluctance in units of the meter-kilogram-second system

The magnetomotive force is determined by the ampere turns, while the reluctance is determined by the dimensions of the coil and the effective length of the air gap g inside the iron shell, Figure 1.

This relationship is as follows:

$$R = \frac{g}{\mu w l} \qquad \text{(IV)}$$

where:

g = effective air-gap length in meters

μ = permeability of air, $4\pi \times 10^{-7}$

w and l = coil width and length in meters

Substituting NI for mmf in equation (III) gives:

$$\phi = \frac{NI}{R}$$

Then, substituting $\frac{g}{\mu wl}$ for R, we obtain the total flux in terms of coil turns, current, and dimensions:

$$\phi = \frac{NI}{\dfrac{g}{\mu wl}} = \frac{NI\mu wl}{g}$$

APPENDIX A—(Cont'd)

Substituting this expression for ϕ in equation (II) gives the flux density as:

$$B = \frac{\dfrac{NI\mu wl}{g}}{wl}, \text{ or}$$

$$B = \frac{NI\mu}{g} \qquad \text{(V)}$$

That is, flux density increases with coil turns and current, but decreases as the air gap is made longer.

The deflection angle θ is increased by increasing the flux density B, or by increasing the coil length l, but is decreased if the second anode voltage is increased. The mathematical expression for this relationship is:

$$\theta = 1.7 \times 10^{7} \frac{lB}{\sqrt{E_A}} \text{degrees.} \qquad \text{(VI)}$$

where:

E_A = difference of potential between the cathode and the second anode in volts.

Finally, to obtain an expression which shows the mmf in ampere turns required to produce a desired deflection angle, when E_A, l, and g are known, we substitute the right side of equation (V) for B in equation (VI):

$$\theta = 1.7 \times 10^{7} \frac{l\dfrac{NI\mu}{g}}{\sqrt{E_A}}, \text{ or}$$

$$\theta = 1.7 \times 10^{7} \frac{NI\mu l}{g\sqrt{E_A}}.$$

Dividing both sides by NI

$$\frac{\theta}{NI} = \frac{1.7 \times 10^{7} \mu l}{g\sqrt{E_A}}$$

APPENDIX A—(Cont'd)

Inverting, and substituting $4\pi \times 10^{-7}$ for μ

$$\frac{NI}{\theta} = \frac{g\sqrt{E_A}}{1.7 \times 10^{7} \times 4\pi \times 10^{-7}\, l}$$

Multiplying both sides by θ, and simplifying the denominator,

$$NI = \frac{\theta g\sqrt{E_A}}{6.8\,\pi l}$$

The reciprocal of $6.8\,\pi$ is .047. Multiplying both numerator and denominator of the right member by this value gives our final form as:

$$NI = \frac{.047\theta g\sqrt{E_A}}{l} \qquad \text{(VII)}$$

STUDENT NOTES

STUDENT NOTES

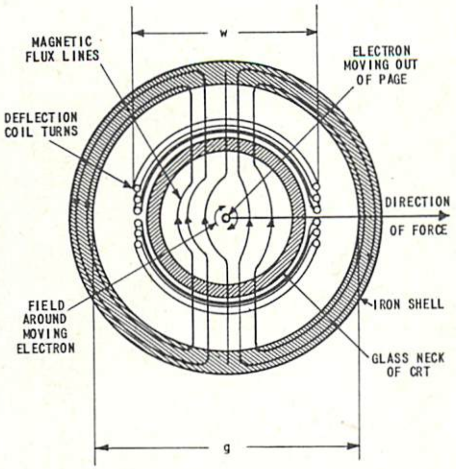


FIGURE 1

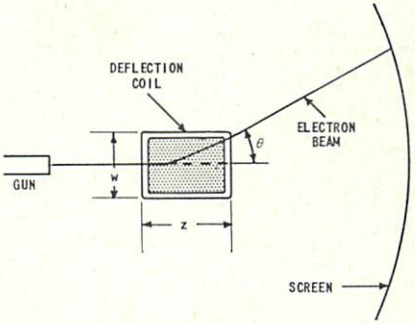


FIGURE 2

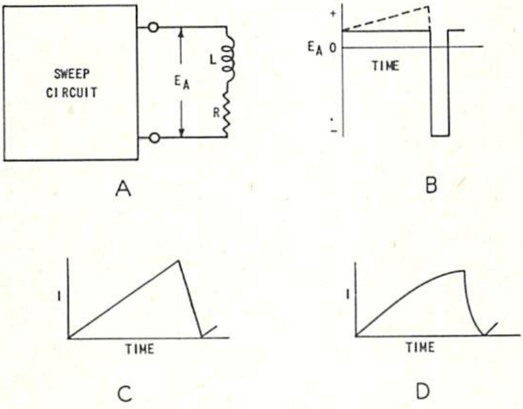


FIGURE 3

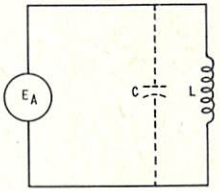


FIGURE 4

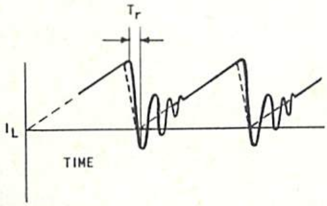


FIGURE 5

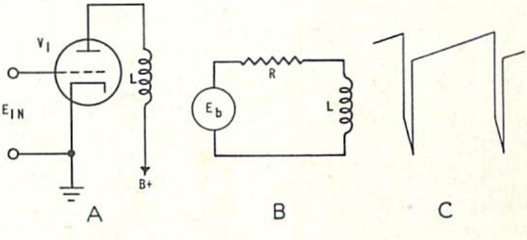
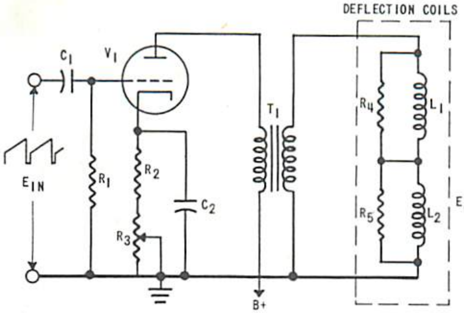


FIGURE 6



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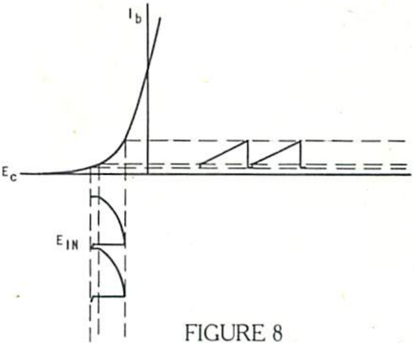

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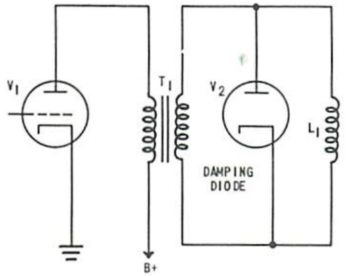

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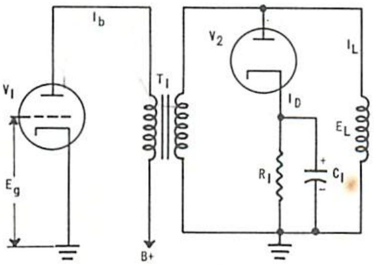

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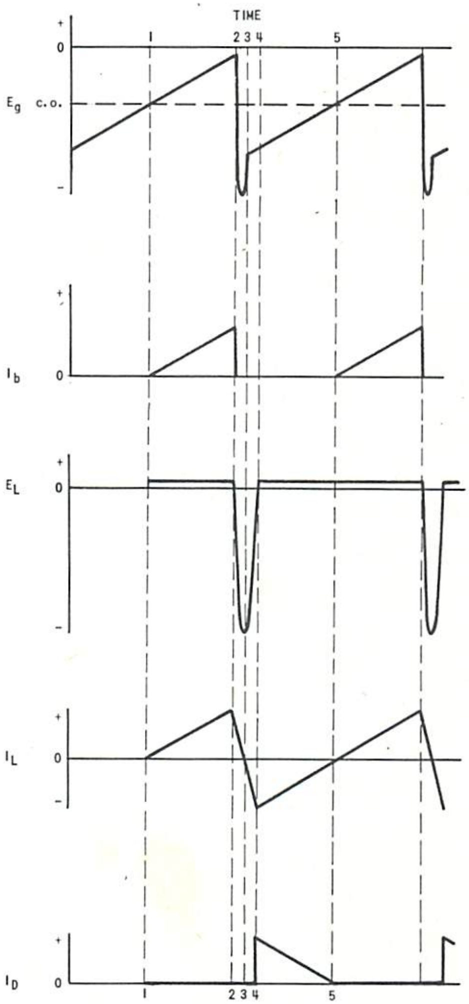

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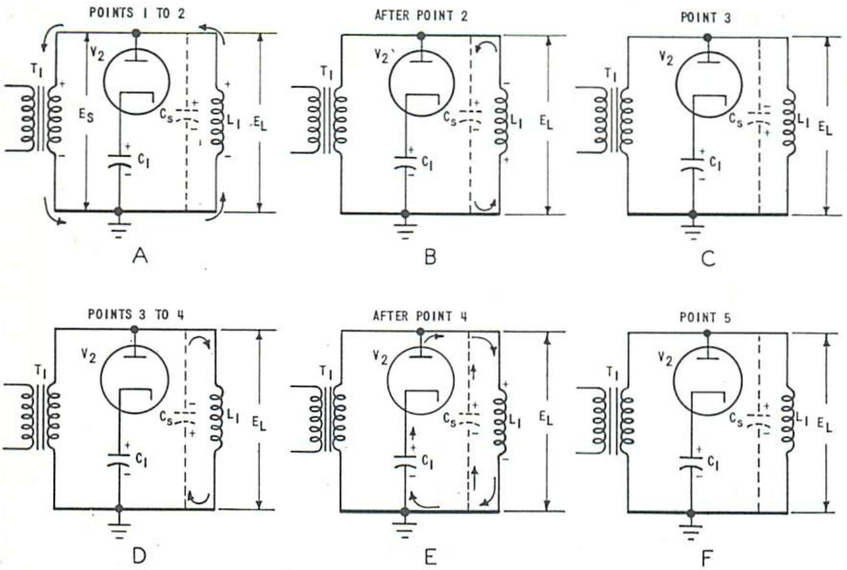

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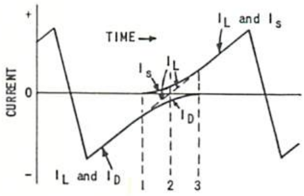


FIGURE 13

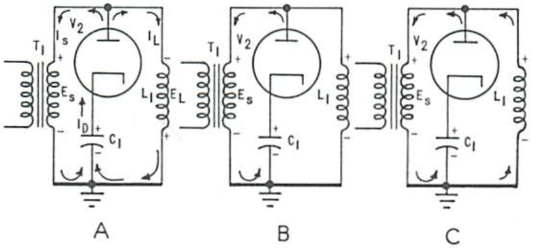
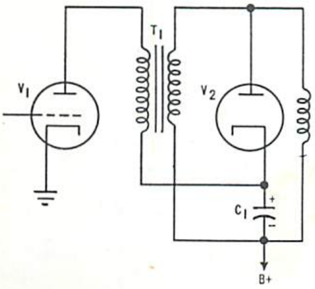


FIGURE 14



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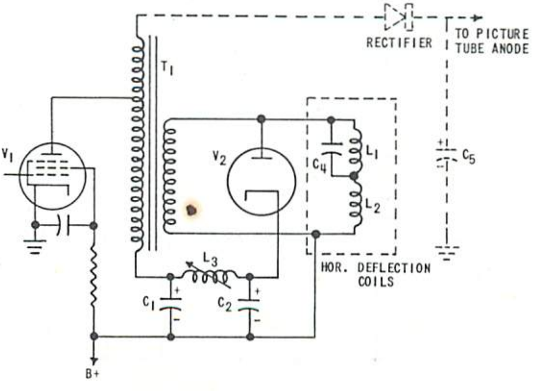

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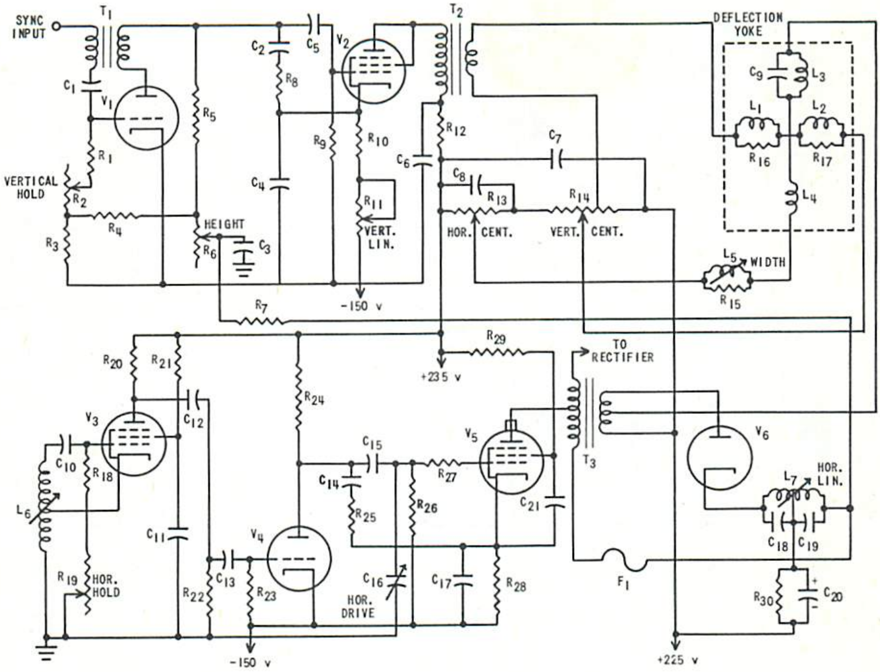

FIGURE 17

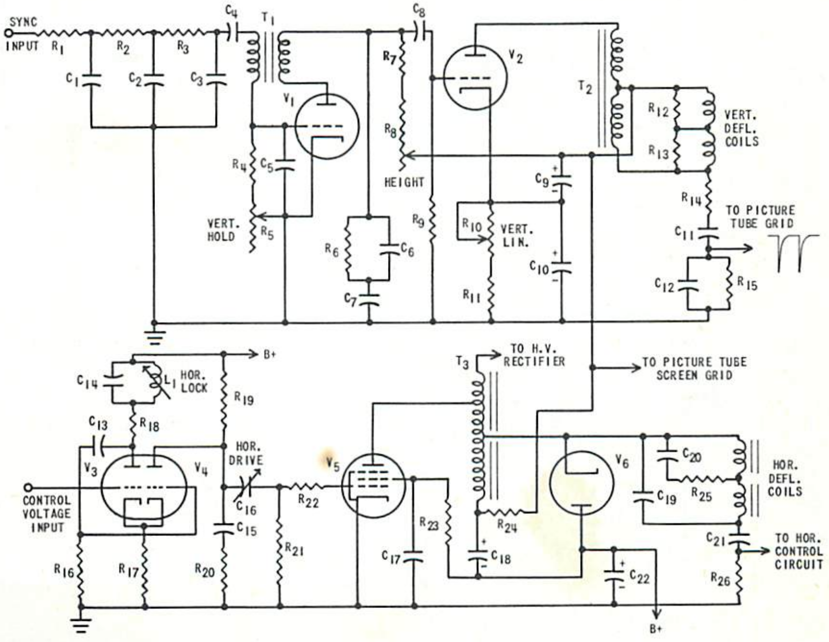

FIGURE 18

FROM OUR *Director's* NOTEBOOK

MAN'S MEASUREMENT

A man's no bigger than the way
He treats his fellow man!
This standard has his measure been
Since time itself began!
He's measured not by tithes and creeds,
High-sounding though they be;
Nor by the gold that's put aside,
Nor by his sanctity!
He's measured not by social rank,
When character's the test;
Nor by his earthly pomp or show,
Displaying wealth possessed!
He's measured by his justice, right,
His fairness at his play,
His squareness in all dealings made,
His honest, upright way.
These are his measures, ever near
To serve him, when they can;
For man's no bigger than the way
He treats his fellow man!

Yours for success,

W. C. DeVry

DIRECTOR

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